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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEROLOGICAL CENTER

Office Note 292

Objective Determination of the Maximum Wind Speed and Level Using a Cubic Spline Technique

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INTRODUCTION

During the past several years, NMC, in response to interest expressed by the International Civil Aviation Organization (ICAO), developed two numerical methods for finding the maximum wind speed (MW) and the pressure level of the maximum wind (PMW). The first (old) method, which uses a quadratic polynomial technique, was developed in 1981 by Stackpole and described in NMC Office Note 229 (Ref. 1). Tests and evaluations in 1982 (Ref. 2) revealed that this method produces reasonable and reliable data. The second (new) method, which uses a cubic spline technique to calculate the maximum wind is the topic of this Office Note.

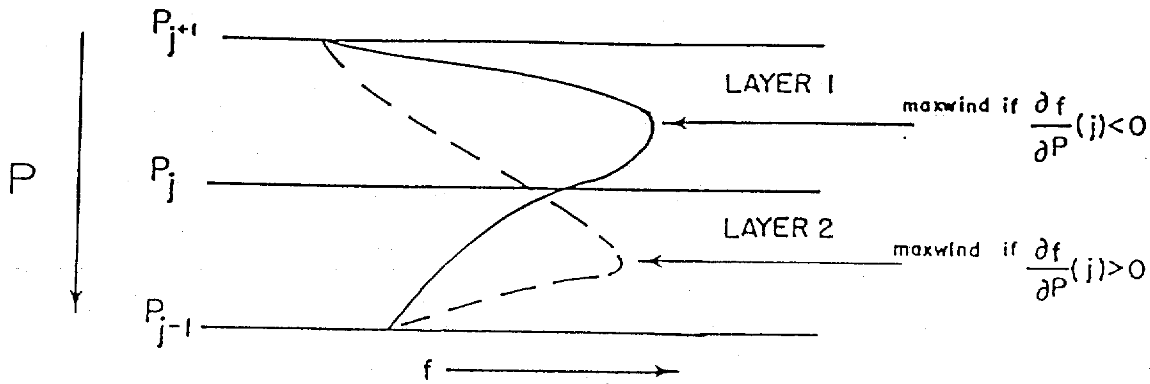
The cubic spline method described here is patterned after the maximum wind finder used in the 15-level forecast model at the British Meteorological Office (Bracknell). The major difference between Bracknell's and NMC's method is that Bracknell uses data at sigma levels while NMC uses data at mandatory pressure levels. A description of Bracknell's method can be found in an article written by Watkins *et al*, June 1983 (Ref. 3).

This paper presents a brief description of the method used at NMC, an example, and a statistical summary.

CUBIC SPLINE METHOD

The cubic spline method for determining the maximum wind speed and the associated pressure level uses, as input, spectral model forecasts of u and v wind components at mandatory pressure levels. For our purposes, the level of max wind speed is calculated, not the level(s) of maximum u and maximum v. Also, the level is constrained to the layer between 500 and 100mb.

At each spectral model gridpoint, wind speeds are derived from the u and v components at seven mandatory pressure levels, i.e., 500 mb, 400 mb, 300 mb, 250 mb, 150 mb, and 100 mb. Then the level with the largest speed (P_j) is determined. The max wind is assumed to be either in the layer above or below level P_j (layer 1 or 2 in the diagram that follows).



In order to decide between layers, a cubic spline is fitted to the wind speed at the seven levels, and the first derivative is evaluated at level P_j. If the first derivative is negative, the max wind is presumed to be in the layer above P_j (between levels P_j and P_{j+1}). If the first derivative is positive, the max wind is presumed in the layer below P_j (between levels P_{j-1} and P_j). The exact location of the max speed level ($\frac{\partial f}{\partial P}=0$, where f is the wind speed derived from the cubic spline) is derived by the formula below. For example, if the max wind is assumed to be in layer 1 (see diagram), then:

$$PMW = \frac{\left(P_j\left(\frac{\partial^2 f}{\partial P^2}\right)_{j+1} - P_{j+1}\left(\frac{\partial^2 f}{\partial P^2}\right)_j \pm A^{\frac{1}{2}} \right)}{\left(\frac{\partial^2 f}{\partial P^2}\right)_{j+1} - \left(\frac{\partial^2 f}{\partial P^2}\right)_j}$$

$$\text{where } A = \frac{1}{3}\left(P_{j+1} - P_j\right)^2 \left\{\left(\frac{\partial^2 f}{\partial P^2}\right)^2_{j+1} + \left(\frac{\partial^2 f}{\partial P^2}\right)_{j+1}\left(\frac{\partial^2 f}{\partial P^2}\right)_j + \left(\frac{\partial^2 f}{\partial P^2}\right)^2_j\right\}$$

$$-2\left(f_{j+1} - f_j\right)\left\{\left(\frac{\partial^2 f}{\partial P^2}\right)_{j+1} - \left(\frac{\partial^2 f}{\partial P^2}\right)_j\right\}$$

If the max wind is determined to be in layer 2, then the subscripts j and j+1 in the equation above become j-1 and j, respectively. Since the evaluation of PMW leads to two results depending upon the choice of the positive or negative square root, the PMW value chosen is the one that lies within the desired layer.

Finally the value of the cubic spline at the pressure level PMW is the speed of the maximum wind (MW). An MW and PMW is evaluated for all gridpoints in the field.

After the max wind speed and the associated pressure level have been determined, the direction of the max wind is obtained by linear interpolation (in log P) between the wind directions at the adjacent pressure levels. Then the max wind direction and speed are used to compute the u and v wind components of the max wind.

An important exception is made whenever the largest wind speed at mandatory levels occurs at 100 or 500 mb. If the greatest wind speed is found at the 100 mb level and the computed derivative is negative, the wind speed and direction at that level is defined to be the max wind. Likewise, if the greatest speed is found at 500 mb and the derivative is positive, the wind speed and direction at 500 mb is the max wind.

EXAMPLE

Only one example, 1200 GMT 6 November 1983, out of the many inspected, is presented. In order to improve the aesthetics of the gridprinted or contoured maps, PMW fields were twice smoothed using NMC's "operational" 9-point smoother-desmoother. The MW fields were not smoothed. To further improve the appearance of the experimental output maps, contours on both MW and PMW charts were suppressed wherever speeds were less than 70 knots. (Previous experiments (Ref. 1 and 2) showed that the 70 knots isotach is the boundary between the chaotic and coherent regions of the max level (PMW) map.)

Figure 1, which shows the 250 mb height-isotach analysis for 1200 GMT 6 November 1983, is included for reference. PMW and MW gridprinted fields using data from the operational analysis file, forecast model initialized (F00) file and the 24 hour forecast file are shown in figures 2a - 2b, 3a - 3b, and 4a - 4b, respectively. The MW fields are in knots, countoured in 20 knot intervals and the PMW fields are in millibars, contoured every 100 mb.

In general, overall patterns appear to be quite satisfactory, particularly over strong jet stream areas. As may be expected, however, there is some loss of intensity observable using data from the F00 file. This results from the necessity of interpolating from model layers to mandatory pressure levels.

STATISTICAL EVALUATION

In an effort to examine the method, the cubic spline technique was tested on observational data from many periods. The data were extracted from radiosonde station reports found between 20 - 60°N latitude and 10 - 170°W longitude. To be useful, the report had to contain (1) seven levels of mandatory data (500 - 100 mb) and (2) maximum wind and pressure level information. If there was more than one max wind (between 500 - 100 mb) reported, the wind with the greatest speed was selected.

At each radiosonde station that contained a report which satisfied the above criteria, the seven mandatory level wind speeds were used as input to the max wind finder code and max wind speed and pressure level were computed. Then the calculatd wind data were compared to the observed wind data and differences were formed (i.e. calculated minus observed). These differences formed the data base from which mean (bias) and root-mean-square (rms) statistics were generated. Only observed and calculated wind speeds in excess of 70 knots were used in compiling the statistics.

Figure 5 shows calculated and observed max wind differences for the period 0000 GMT 1 January to 0000 GMT 6 January 1984. Mean (bias) difference is shown by the solid line and root-mean-square (rms) difference by the dashed line. As is evidenced, calculated and observed winds compare quite favorably even though the calculated winds are 2-4 knots weaker. Shallow layers of maximum wind occuring between mandatory pressure levels generate the largest difference in speeds. Up to twenty knots difference was noted in several reports.

Mean (solid line) and rms (dashed line) difference between calculated and observed PMW are presented in figure 6. In general, differences amount to only 10 mb. The occurrence of more than one layer of max wind is responsible for providing the largest error (about 100 mb) in locating the max wind level.

Statistics compiled for other periods revealed similar results.

CONCLUDING REMARKS

Overall, the test results showed that the cubic spline technique is an adequate means of determining the maximum wind speed and its level. Its performance is comparable to the old method. It has the advantage, however, of being computationally less expensive. It saves at least seven seconds of computer time per map.

This new method was implemented operationally on 23 May 1984. Examples of the maps produced operationally for the Aviation Branch at NMC are shown in Figures 7 and 8. The figures show the max wind contours in 20 knot intervals (beginning at 70 knots) and levels (small numbers) in hundredths of feet, with the last two digits omitted. A 250 mb height-isotach analysis chart (figure 9) is included for reference.

ACKNOWLEDGEMENTS

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REFERENCES

Stackpole, John, D.: "How to manufacture charts of the maximum wind speed and level of maximum wind", Office Note 229, March 1981.

Johnson, Joseph: "Evaluation of the maximum wind value and level finder code", Office Note 257, June 1982.

Watkins, F. M., J. E. Woods, J. Turner and R. A. Bromley: Met O 2b working Paper No 20," Output Modelling for the 15-level forecast model".

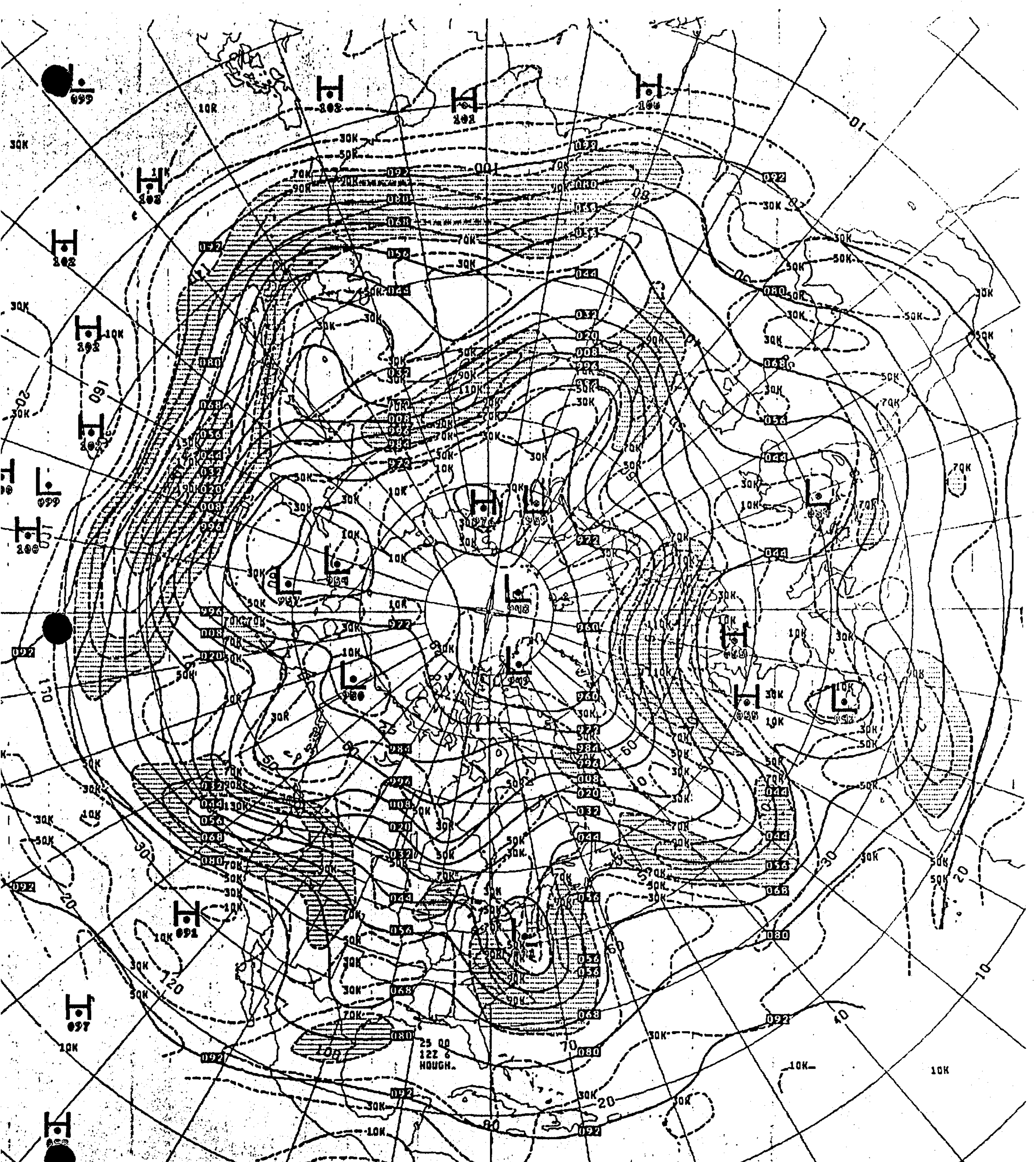

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FIG. 1

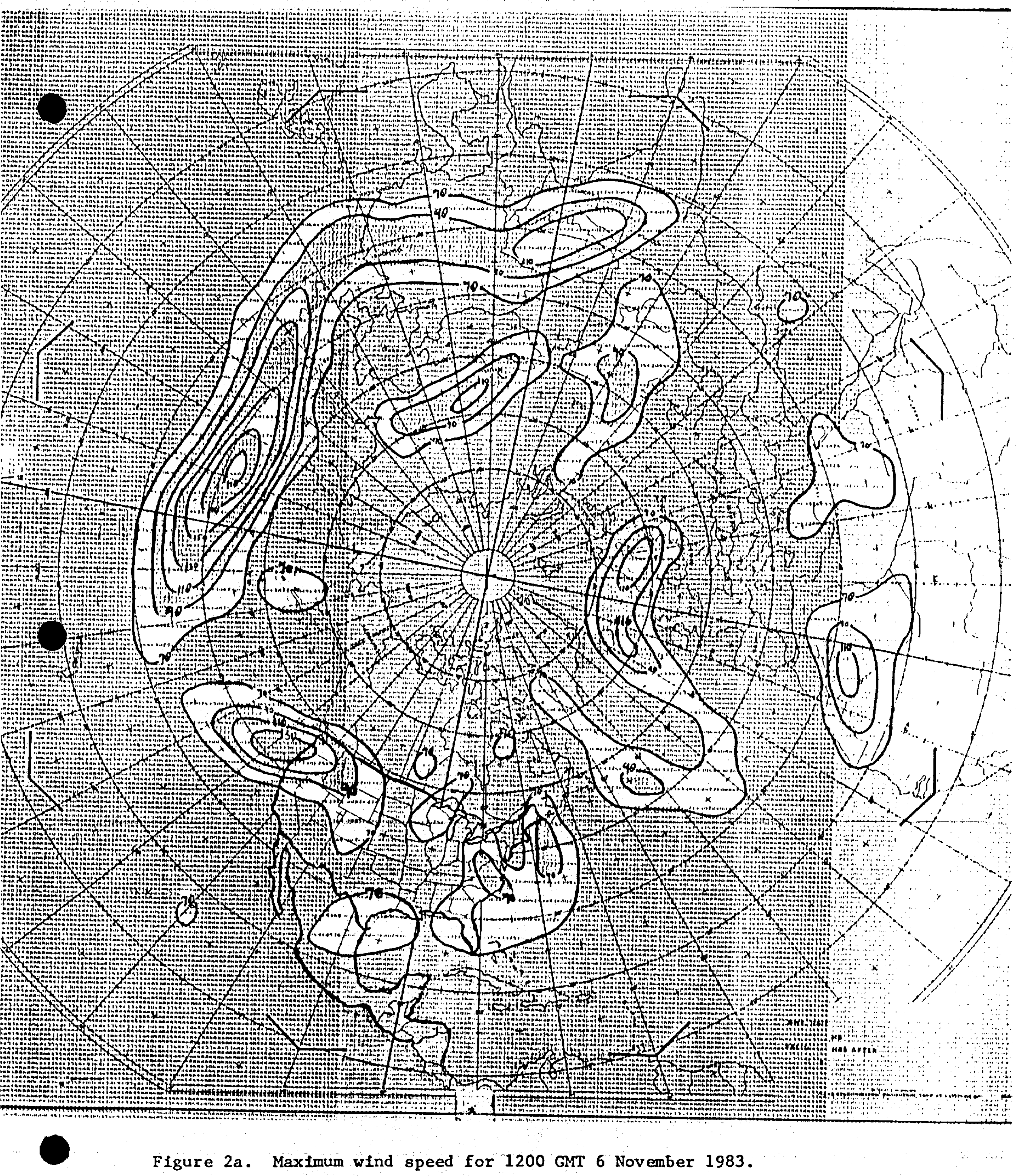


Figure 2a. Maximum wind speed for 1200 GMT 6 November 1983.

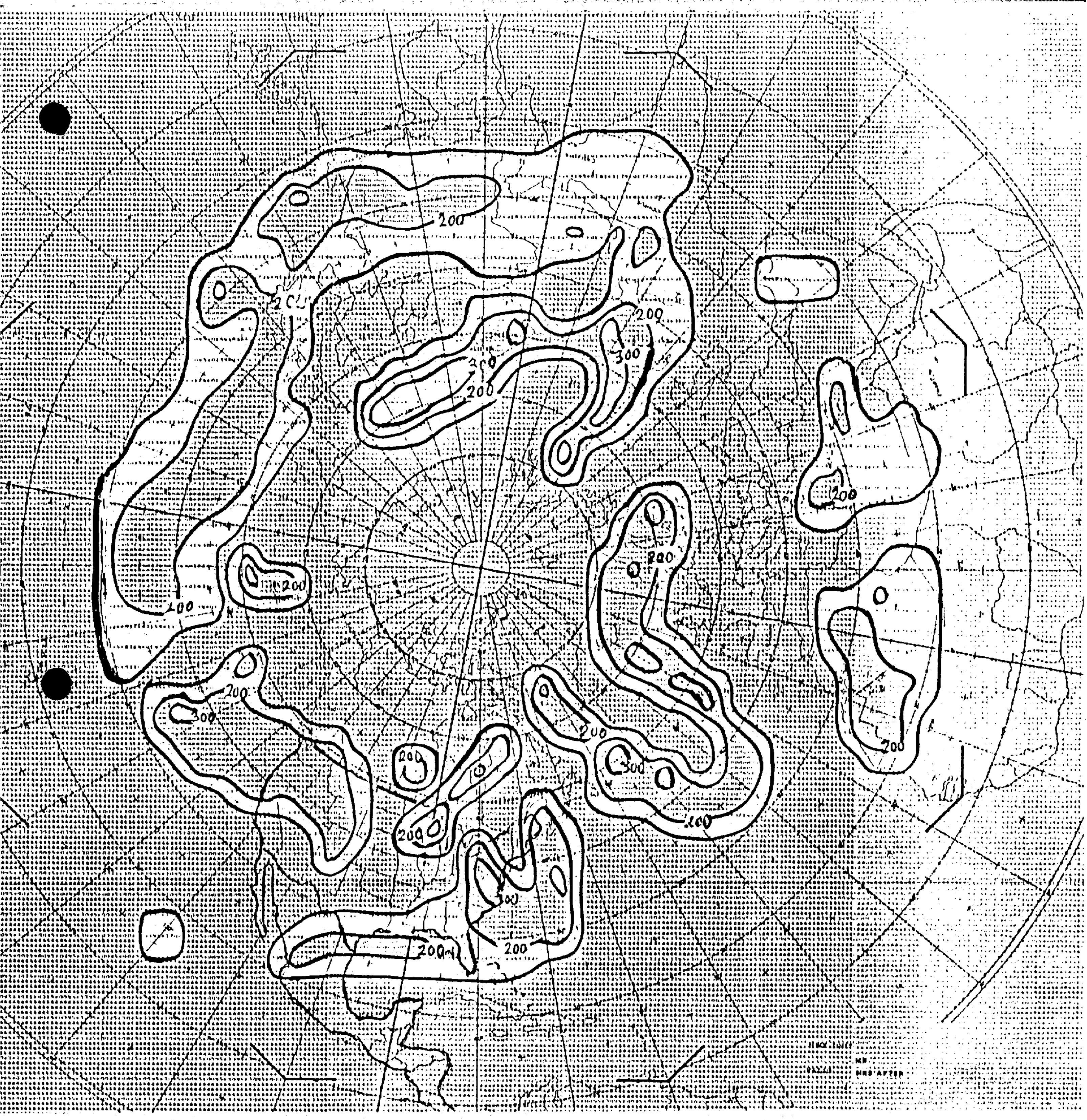


Figure 2b. Maximum speed level pressure for 1200 GMT 6 November 1983.

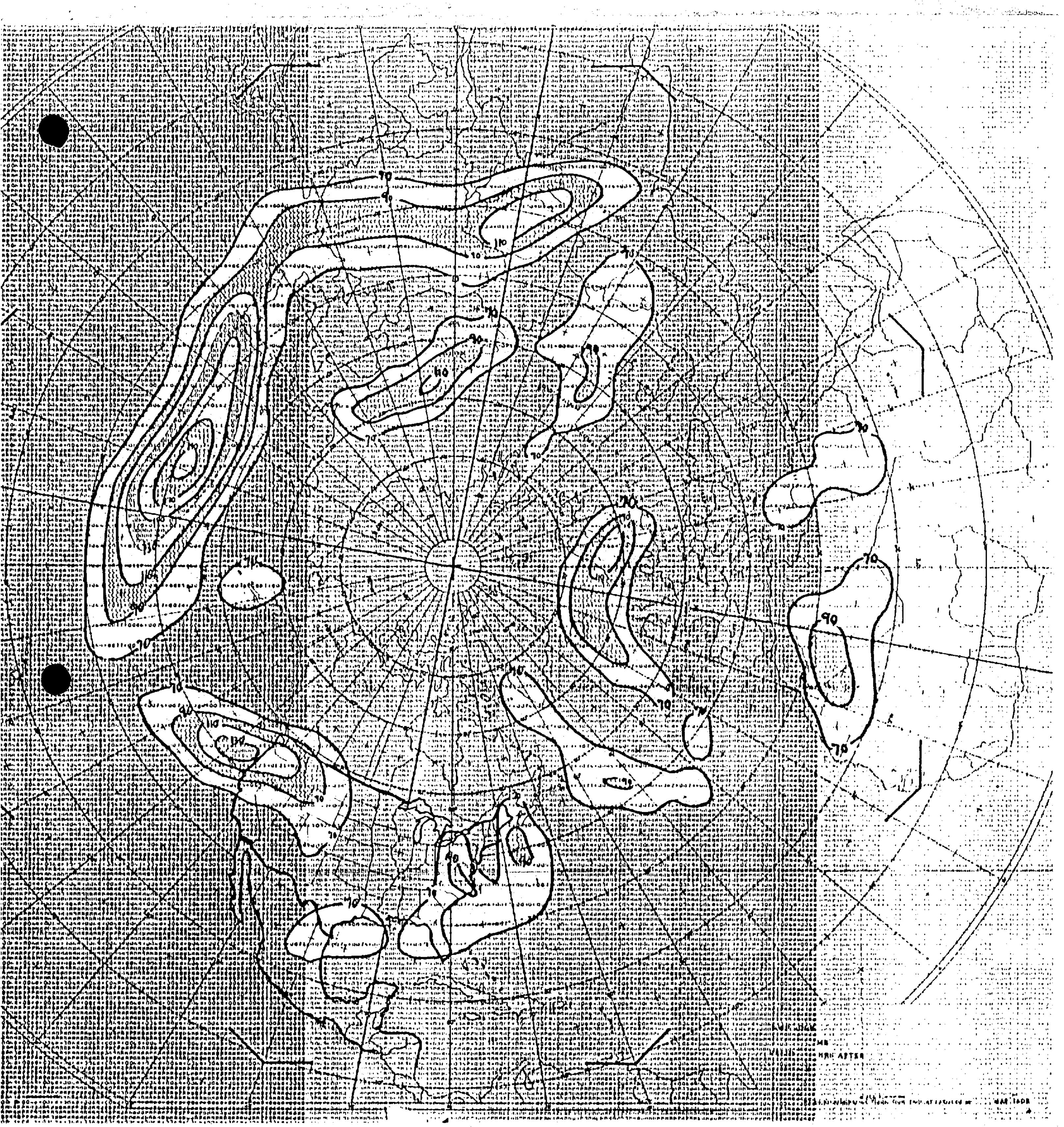


Figure 3a. Maximum wind speed for 1200 GMT 6 November 1983 (from F00 file).

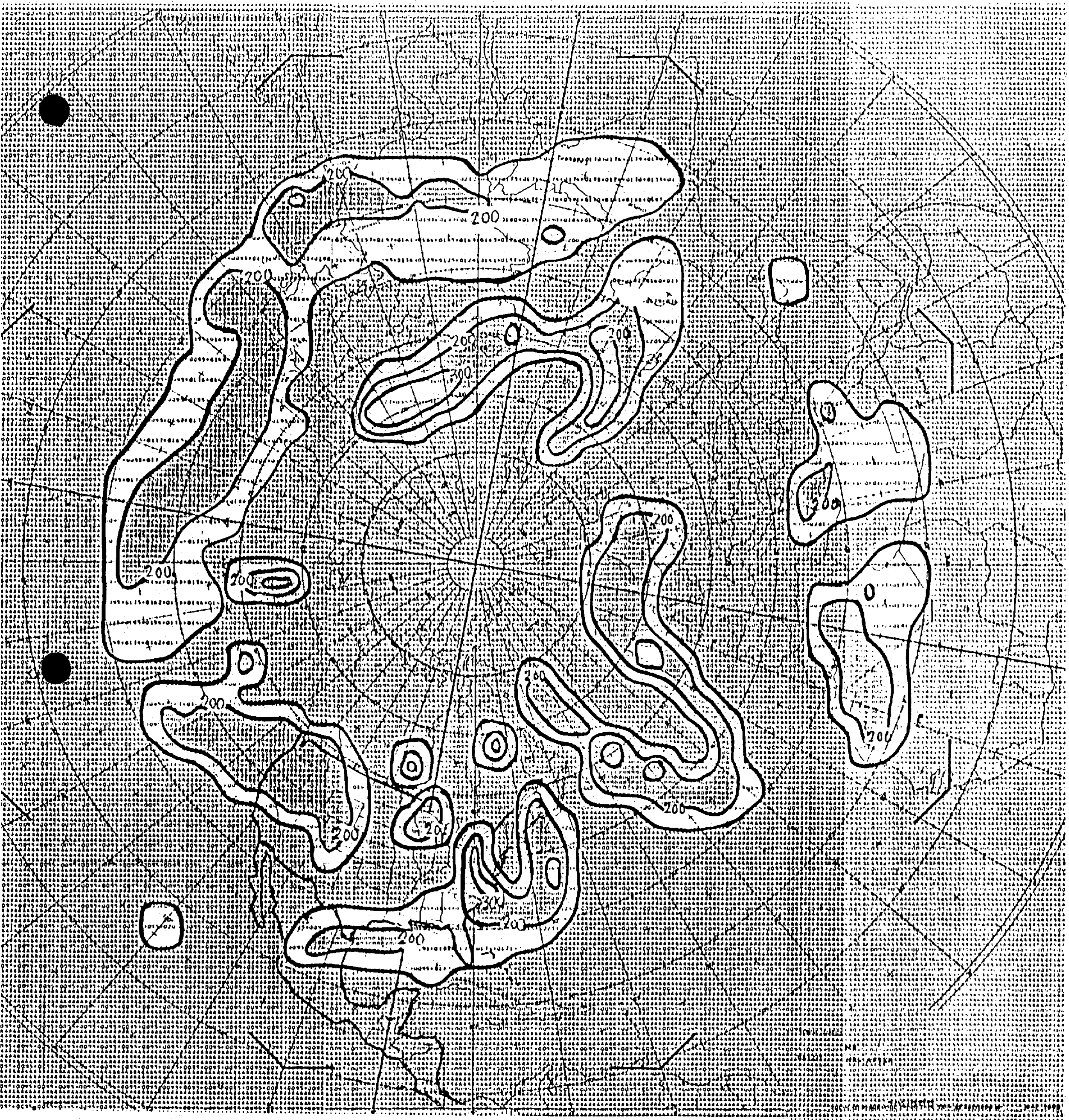


Figure 3b. Maximum speed level pressure for 1200 GMT 6 November 1983

(from F00 file).

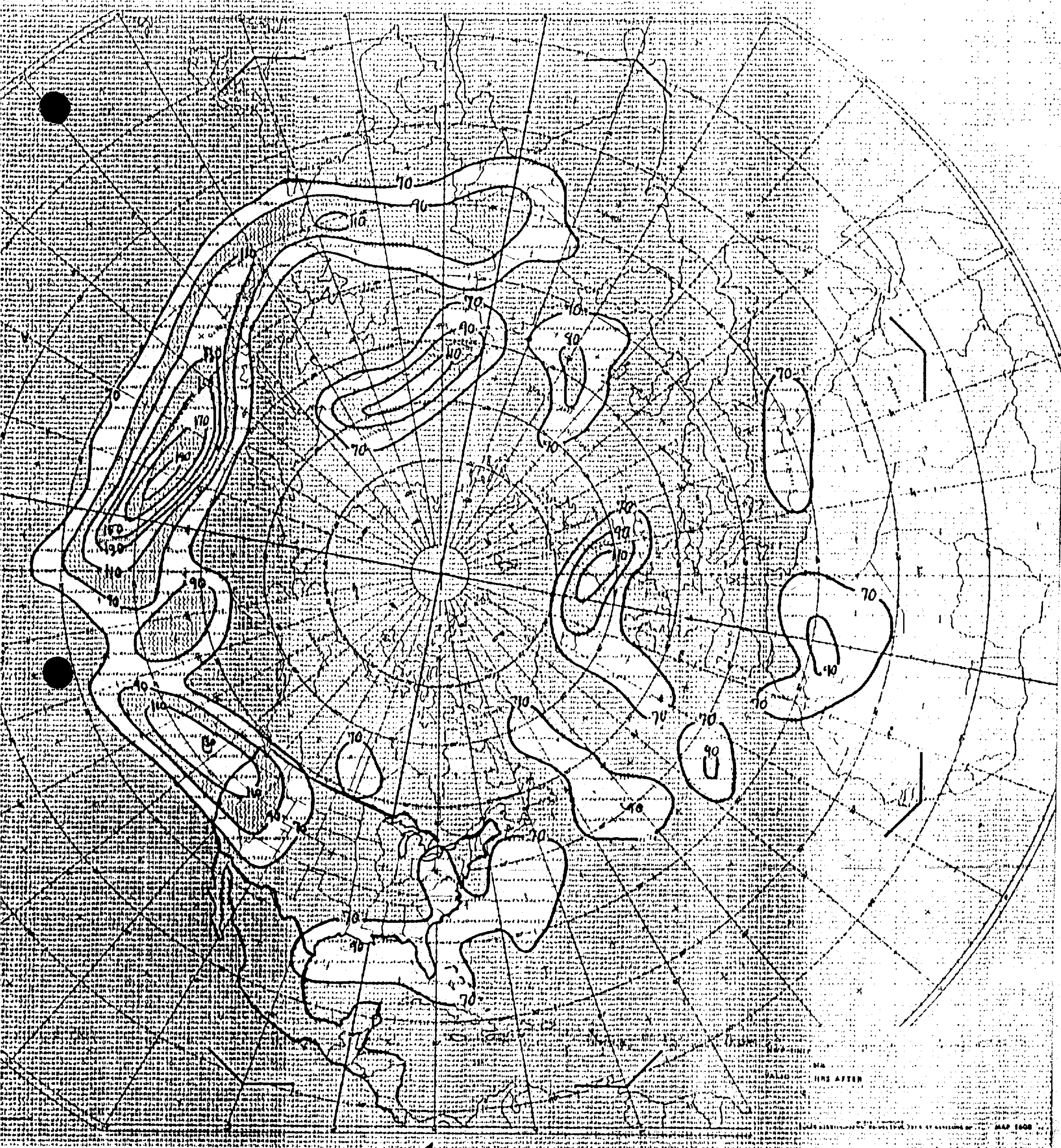


Figure 4a. 24 hour forecast of maximum wind speed [illegible]

valid 1200 GMT 6 November 1983.

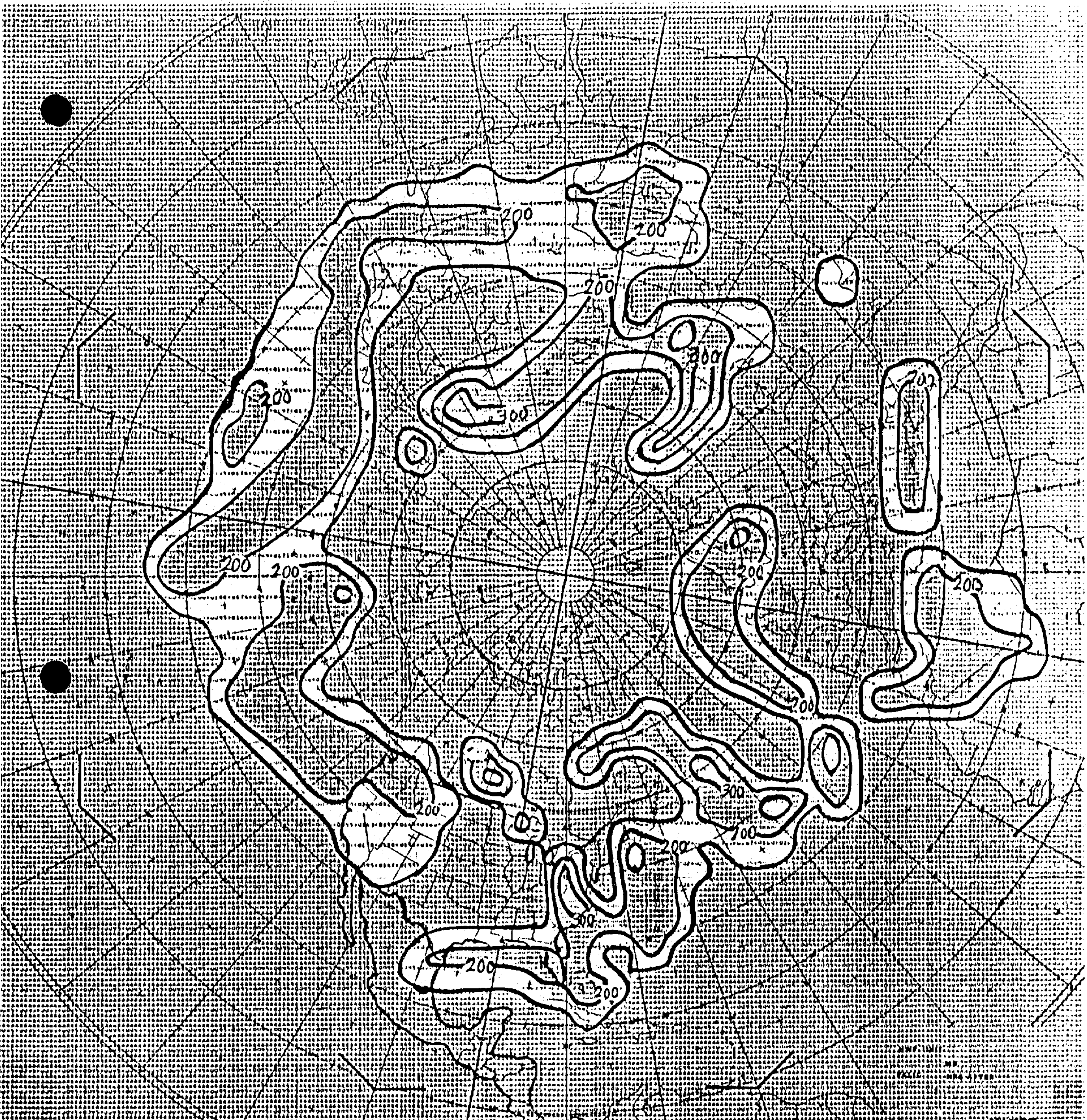


Figure 4b. 24 hour forecast of maximum speed level pressure valid 1200 GMT 6 November 1983.

FIG 5: RMS AND MEAN WIND SPEED DIFFERENCE VS DAY OF MONTH

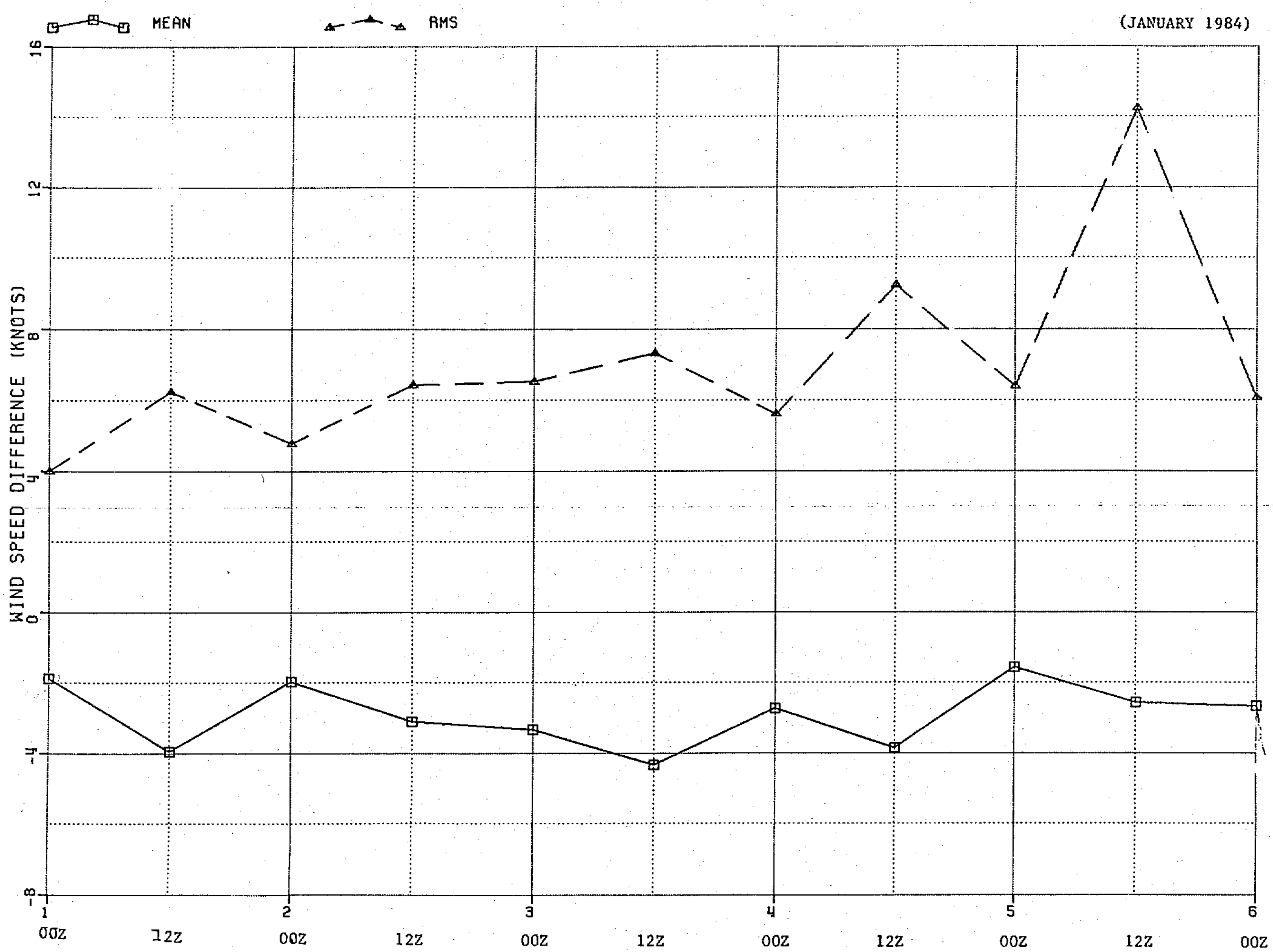
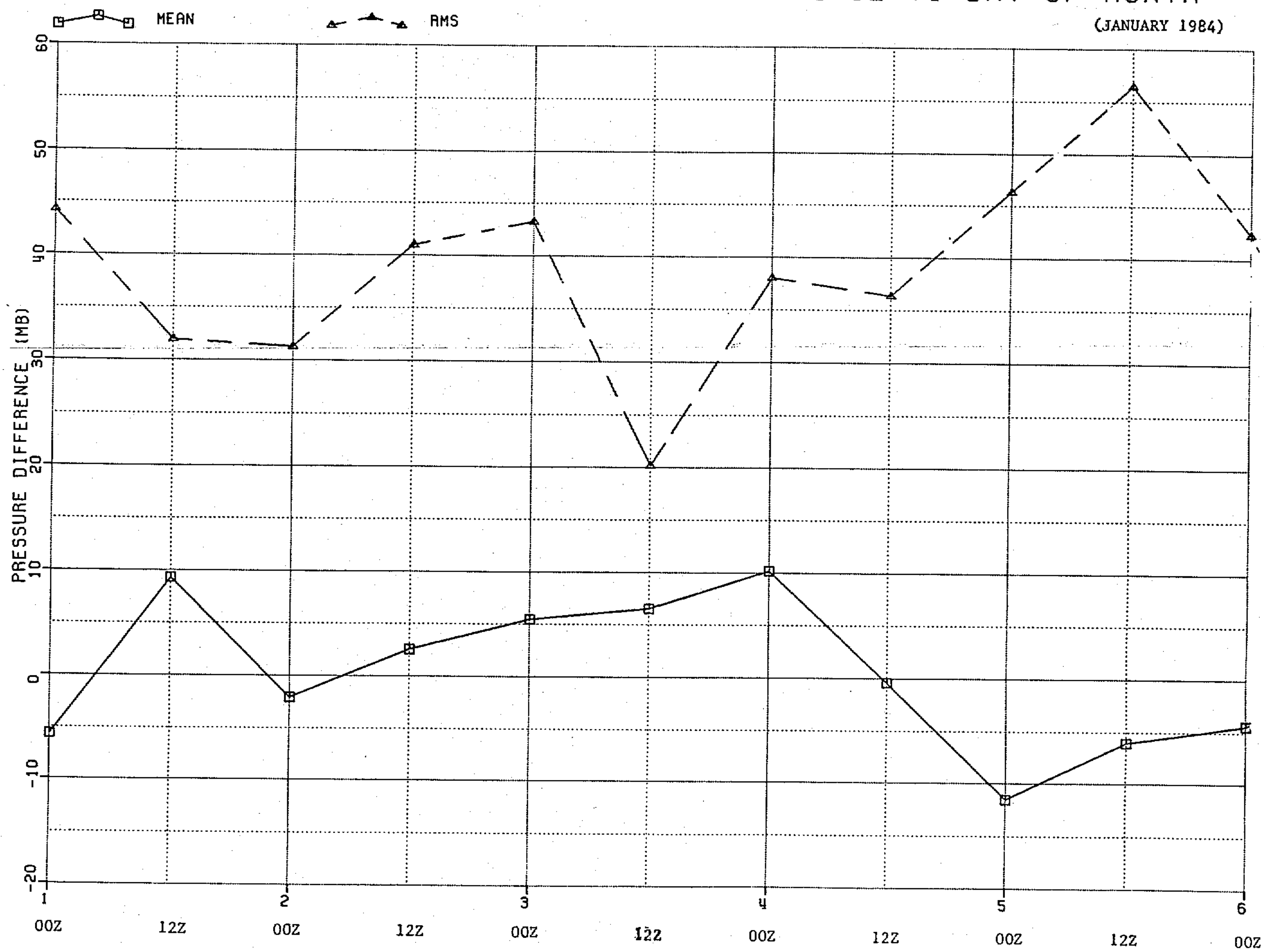


FIG 6: RMS AND MEAN PRESSURE DIFFERENCE VS DAY OF MONTH



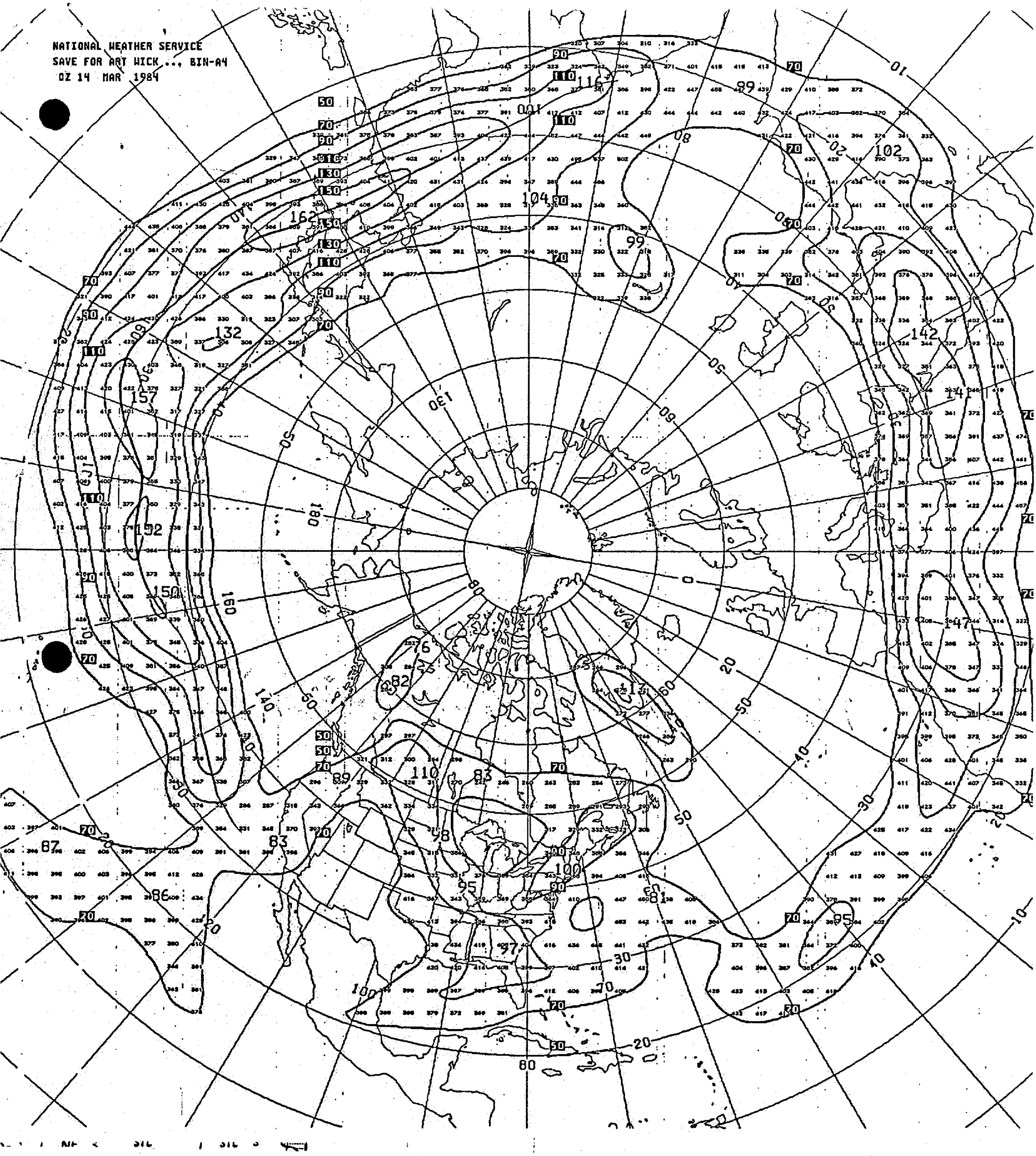


Figure 7. Maximum wind speed (contoured in 20 knot intervals) and level (in hundredths of feet, with last two digits omitted) for 0000 GMT 14 March 1984. (from operational analysis file)

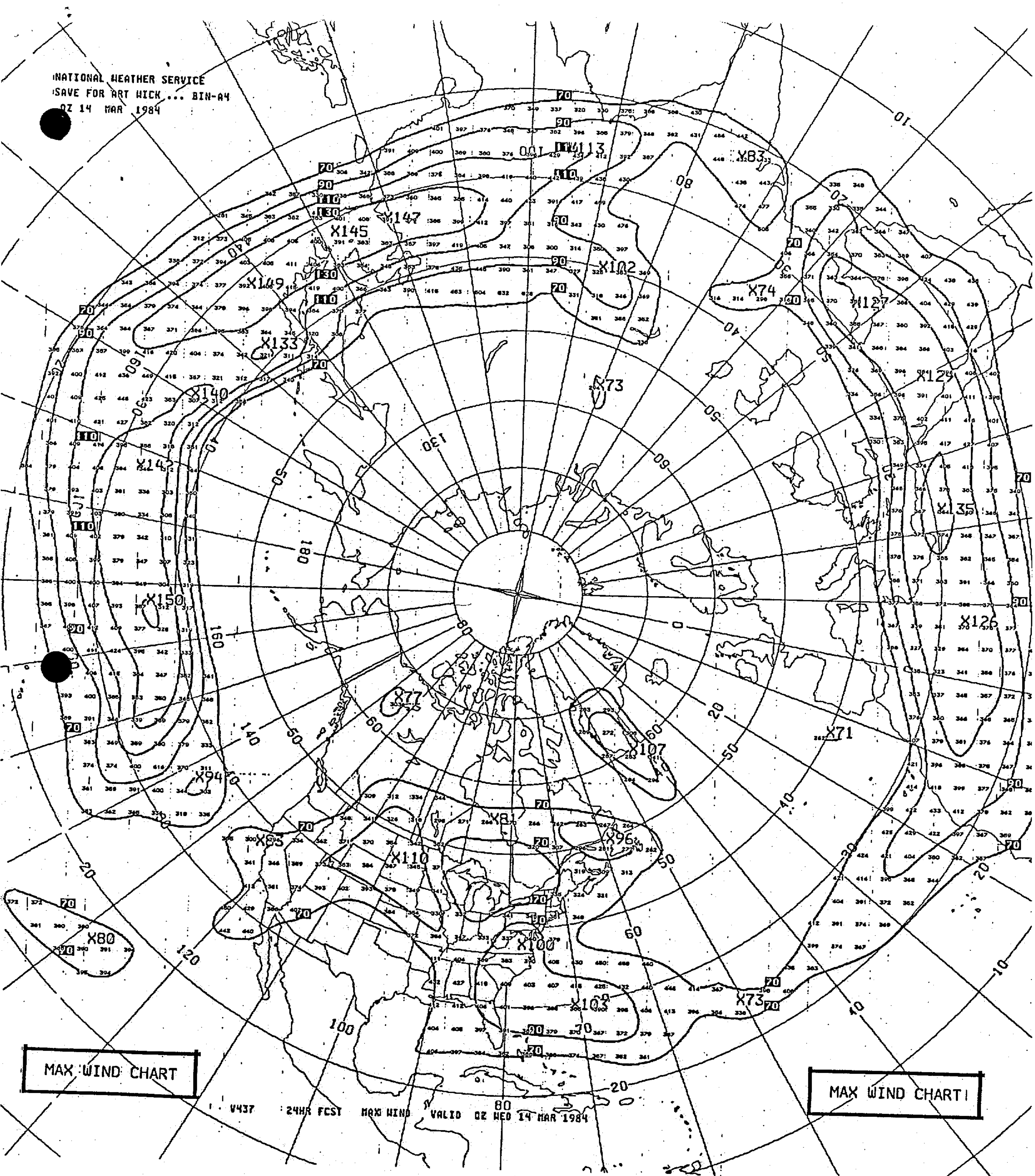


Figure 8. 24 hour forecast of maximum wind speed and level valid 0000 GMT 14 March 1984.

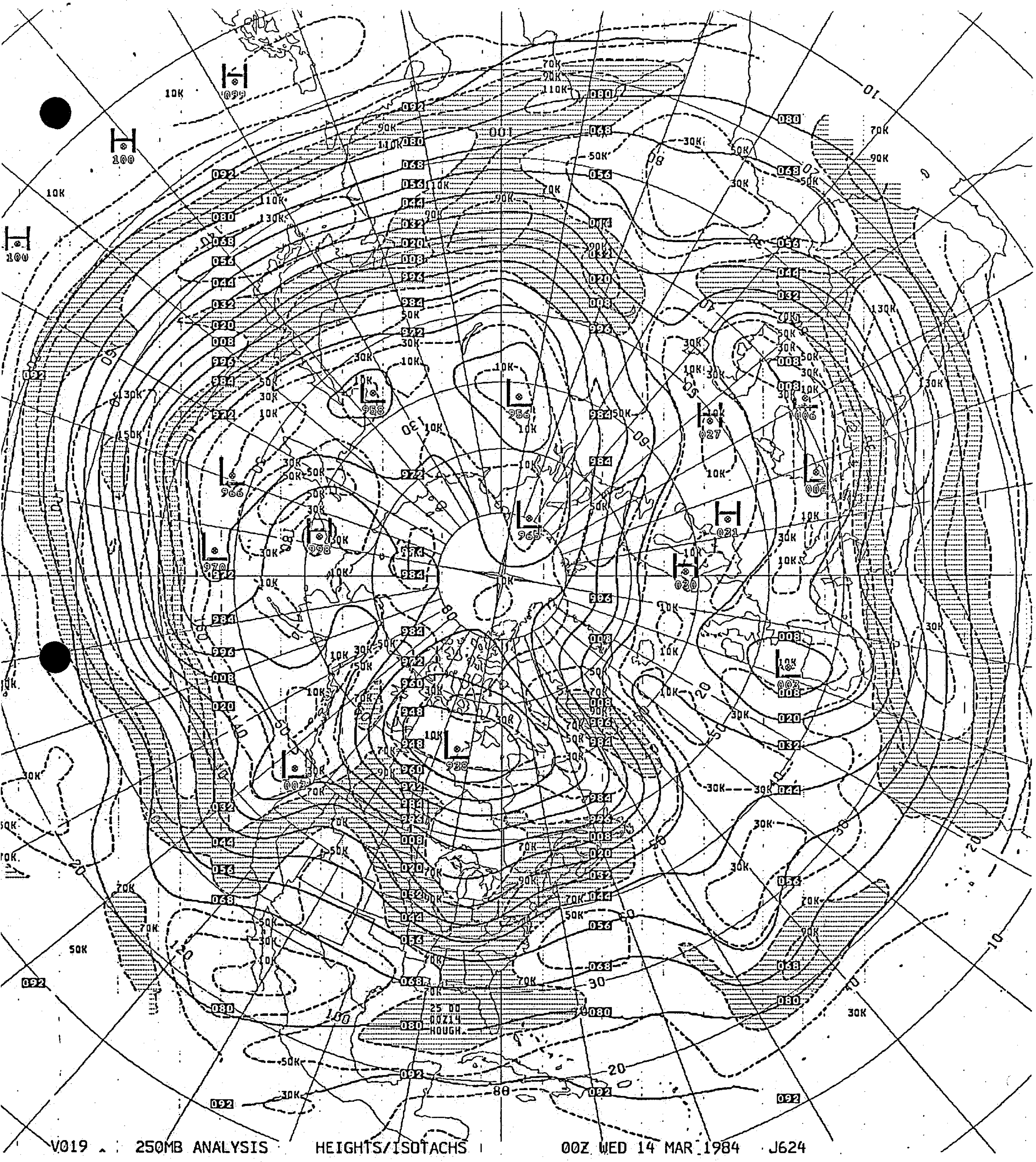

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FIGURE 9